

# Carbon Cycle, Ecosystems, and Biogeochemistry

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# Carbon Cycle, Ecosystems, and Biogeochemistry

## Critical Science Questions

**Existing Roadmaps:** *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- Southern Ocean Carbon Program
- Physiology and Functional Groups – high spatial resolution; diurnal studies
- New Ocean Carbon / Coastal Event Observations
- High-Resolution Atmospheric CO<sub>2</sub>

**Other Roadmap Possibilities:** *Are there other things that should be in the Roadmap now that we see what is possible?*

- Disturbance assessment, monitoring and recovery
- Particulate/black carbon – land-air interface
- Lower troposphere measurements (100m and down) – resolve deposition models
- Boundary layer, tropospheric measurements
- Instabilities in carbon sources and sinks – ie. permafrost
- Wetlands and surface inundation studies – CH<sub>4</sub>
- Global land use change
- Coastal event observations and land-ocean interface – resolving horizontal rather than vertical resolution (improved spatial and temporal resolution), multiple sensor integration
- Comprehensive oceanic survey of carbon cycling
- Process studies on inorganic component of soil carbon

# Carbon Cycle, Ecosystems, and Biogeochemistry

## Critical Science Questions

**Phasing Observations:** *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

- Time series measurements of surface to atmosphere gas flux
  - Co<sub>2</sub> and O<sub>2</sub> measurements – separate out land vs. ocean fluxes
  - Vertical resolution of column Co<sub>2</sub> (OCO validation)
- Vegetation structure/composition, height measurements, ocean surface characterization (ie. roughness, surface height)
  - Improved characterization of biomass (terrestrial & oceanic) using hyperspectral imagery, LIDAR, Radar, passive microwave, Interferometric radar (p, x, band – veg), (ku – ocean surface), (wide-swath ocean altimeter validation)
- Quantify atmospheric particulate matter (eg. black carbon) and aerosols originating from biomass combustion
- Observations of the lower troposphere to constrain boundary layer
- Observations of permafrost condition and change using radar
- Fluorescence measurements over land and ocean to discern functional groups and physiology
- Sea surface salinity measurements for ocean circulation (Aquarius validation)
- Hurricane impacts affects on carbon cycle (plankton blooms, sea-air co<sub>2</sub> exchange, coastal)
- Coastal event observations and land-ocean interface – resolving horizontal rather than vertical resolution (improved spatial and temporal resolution), multiple sensor integration

## **Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations**

**Critical Observation:** Coastal ocean observations: Resolving horizontal and vertical resolution (improved spatial and temporal resolution), multiple sensor integration

**Observation / Measurement Definition:** Describe the phenomenon you want to observe. Describe what you need to measure.

Science Questions:

- How do coastal blooms change over time and space and what is their composition?
- How can we measure estuarine condition?
- How are nutrients consumed and released in the coastal zone, and how does this impact the carbon cycle?
- How well can we quantify submerged aquatic vegetation and coral reefs?

Observations:

- Quantify biomass by measuring aspects of aquatic organisms in the coastal zone. (350nm-1000nm)
- Sea surface temperature and profile (1/10<sup>th</sup> of degree)
- Vertical profile of biomass
- Sea surface roughness
- Sea surface salinity

**Explicitly state how this observation and measurement supports this Earth Science focus area.**

- Supports the stated goal of reducing uncertainties in the fluxes and coastal sea dynamics

**Explicitly state the advantage of using a suborbital platform for this measurement.**

- High frequency measurements to resolve temporal variation
- High resolution in space time and spectra.

**Identify other cross-cutting areas impacted by this observation.**

- This mission can be flown in tandem with the co2 flux mission

# **Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations**

**Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:**

**Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)**

- Hyperspectral Sensor – 350nm-1000nm – 25kg, 100w
- Tunable Laser diode – 25kg, 100w
- TIR Sensor – 8-12micron – 25kg, 100w
- Microwave for Salinity (details needed – see Aquarius)
- Scatterometer (Ku band) for roughness
- Deployable underwater vehicle
  - Salinity
  - Temperature at depth
  - Optical properties of water column
  - Chemical pro

**Flight characteristics (location, altitude, endurance, season, frequency).  
Discuss number of platforms, formation flying, or other special flight characteristics.**

Location:

- Areas of interest: North America Coast, Tropics
- From coast to 50-200km (dependent on depth of continental shelf)

Altitude:

- Approx. 40,000ft to avoid commercial traffic
  - Spatial resolutions from 1m-10m
  - Constrained by power of lidar

Endurance:

- 24-hour missions for each season
- Measurements every 20m

Platforms:

- Integrating measurements with underwater vehicles

**Communication needs such as real-time data or instrument control**

- Over-the-horizon command and control and data telemetry
- Near realtime communication with underwater vehicles, buoys to allow for flexibility in tasking
- 20 Mbs

# Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations

**Mission Concept:** Describe in as much detail as possible the measurement approach:

Provide a narrative describing a “day-in-the-life” of the mission.

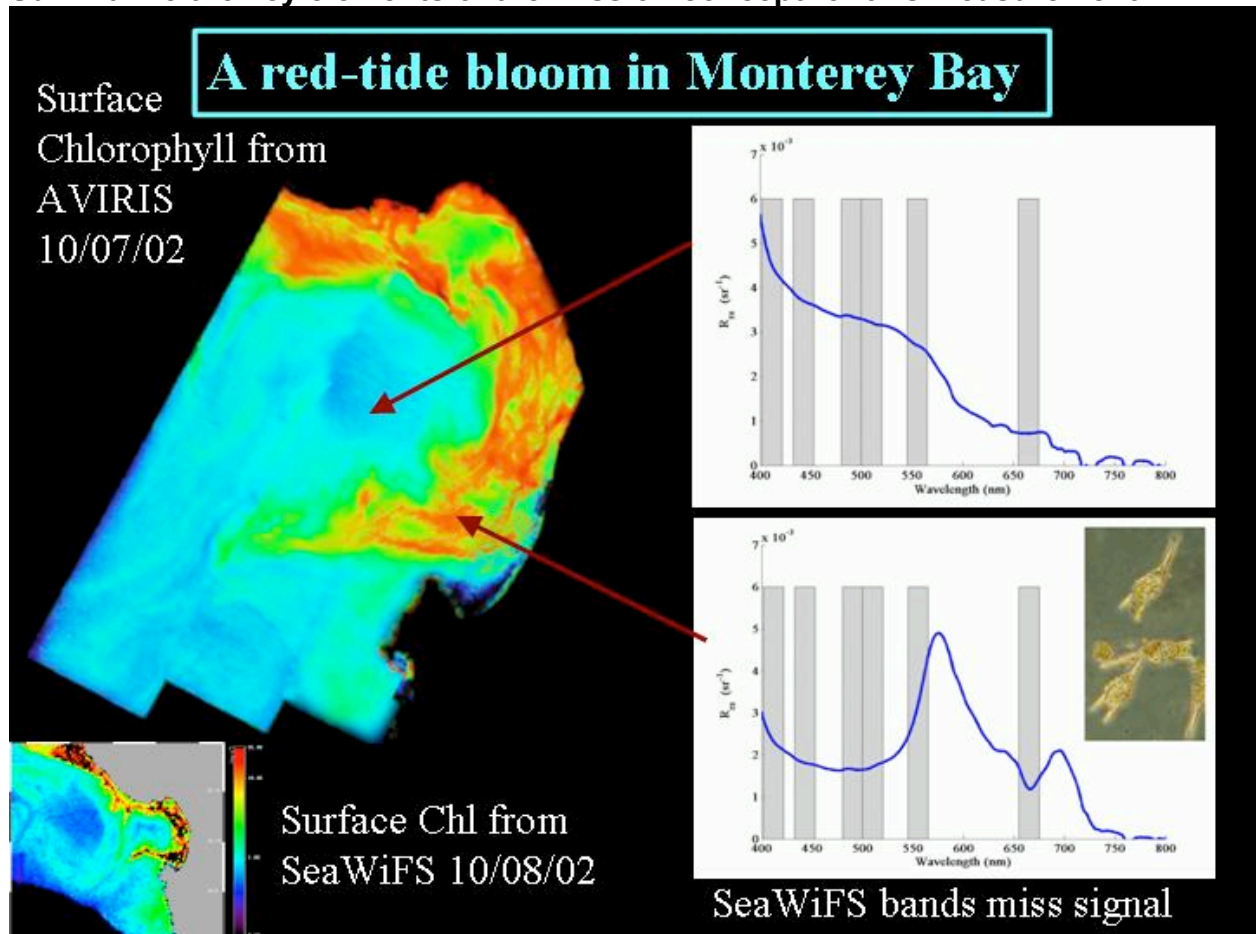
- Cue mission from MODIS/VIIRS ocean color measurements or in situ buoys or following cyclone/hurricane events.
- Aircraft will be deployed before the bloom to observe and measure the development and waning.
- Underwater vehicles will be deployed from air or land.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Loitering mission for bay or estuary; transects for larger coastal regions

Identify any special or unique platform or mission issues  
(no input)

Summarize the key elements of the mission concept for this measurement.



# **Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment**

**Critical Observation:** Active Fire, emissions, and plume assessment

**Observation / Measurement Definition:** Describe the phenomenon you want to observe. Describe what you need to measure.

- Atmospheric chemistry
- Thermal intensity time-series
- Plume composition, volume, albedo, and particle size distribution
- Fuel type and quality

**Explicitly state how this observation and measurement supports this Earth Science focus area.**

- Understanding the influence of disturbance on carbon cycle dynamics

**Explicitly state the advantage of using a suborbital platform for this measurement.**

- Loitering capabilities
- Dangerous & Dirty plume measurements

**Identify other cross-cutting areas impacted by this observation.**

- Atmospheric composition focus area would benefit from a better understanding of chemical constituents of fire plumes resulting from different fuels under different intensities of fire

**Observation / Measurement System Requirements:** Describe how you want to observe or measure the phenomena. Consider the following:

**Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)**

- Isotope ratio mass spectrometers, Gas chromatographer, Non-Dispersive IR Analyzer
  - 50-100kg
  - Accurate IMU – tbd
  - 3D windfield at 10hz or better
  - height and velocity from interferometer?
  - Mind the engine exhaust
  - Ancillary meteorological data (PAR, polarimeter, temperature, humidity, etc)
- Imaging Spectroscopy

## **Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment**

- Hyperspectral (350nm-2500nm), 10nm channels
  - <50kg
  - 0.5 m<sup>3</sup>
  - 200w
  - downward-looking port
  - 5-20m horizontal
  - 5-50km swath
- LIDAR
- Waveform
  - Sufficient to resolve particles ranging from <.05 micron – 20 micron
  - reference solid earth specs (30kg)
  - 600w
  - downward-looking port
  - 1m horizontal; 15cm vertical
  - <3km swath

**Flight characteristics (location, altitude, endurance, season, frequency).  
Discuss number of platforms, formation flying, or other special flight  
characteristics.**

- At least 2 platforms: one for in situ plume measurements (disposable), and the other for fire dynamics (higher altitude)
- Alternative is to drop instruments into the plume or
- Endurance: duration of fire 24-72 hours
- Range: Follow plume from source to deposition (>5000-10000km)
- Season: fire season goes May-September in North America

**Communication needs such as real-time data or instrument control**

- Deployment will be contingent upon human or satellite detection
- Over-the-horizon capability
- Realtime data telemetered to field



## **Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment**

**Mission Concept:** Describe in as much detail as possible the measurement approach:

**Provide a narrative describing a “day-in-the-life” of the mission.**

Deployment cued from MODIS/VIIRS active fire detection or human detection. Flight prep would be determined by fire season and fire risk assessment. Follow dry lightning storms to search for new fires.

Alternatively, a high-altitude, long duration aircraft could loiter over an area for weeks to months, wait for fire, and task lower altitude assets

Prescribed burn would allow for more thorough assessment of pre and post fire carbon mass balance.

**Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.**

*(no input)*

**Identify any special or unique platform or mission issues**

Plume sampling would entail ability to withstand extreme vertical velocities coming off of fire.

Electric propulsion would prevent issues associated with engine air intake and fuel flammability

Frame and sensor materials would need to be fire proof

**Summarize the key elements of the mission concept for this measurement.**

*(no input)*

# **Carbon Cycle, Ecosystems, and Biogeochemistry – Flux Study**

**Critical Science Question:** What is the flux of O<sub>2</sub>, CO<sub>2</sub> and other trace gases between the surface (sea and land) and atmosphere and does it change with space and time?

**Observation / Measurement Definition:** Describe the phenomenon you want to observe. Describe what you need to measure.

Time series measurements of surface to atmosphere gas flux

- Co<sub>2</sub> and O<sub>2</sub> measurements – separate out land vs. ocean fluxes
  - < 0.1 ppm
- Vertical resolution of column Co<sub>2</sub> (OCO validation)
  - Express as a function of atmospheric pressure gradients – resolve differences as low as 10mb
  - Higher resolution required in boundary layer versus mid-upper atmosphere
- Horizontal resolution – 100m for interferometer; 10m for flux measurements
- Minimum duration of 24 hours for diurnal cycle studies

**Explicitly state how this observation and measurement supports this ESE science focus area.**

- Supports carbon cycle science focus area roadmap
- Provide higher resolution data on sources and sinks of atmospheric CO<sub>2</sub> on land and in the ocean
- Provide information to scale up flux measurements from tower networks

**Observation / Measurement System Requirements:** Describe how you want to observe or measure the phenomena. Consider the following:

**Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)**

- Isotope ratio mass spectrometers, Gas chromatographer, Non-Dispersive IR Analyzer
  - 50-100kg
  - Accurate IMU – tbd
  - 3D windfield at 10hz or better
  - height and velocity from interferometer?
  - Mind the engine exhaust
  - Ancillary meteorological data (PAR, polarimeter, temperature, humidity, etc)

## **Carbon Cycle, Ecosystems, and Biogeochemistry – Flux Study**

- Upward looking Michelson interferometer (“inverse TES”) - 4 micron band
  - o 50kg
  - o upward viewing port
  - o low altitude as possible

**Flight characteristics (location, altitude, endurance, season, frequency).  
Discuss number of platforms, formation flying, or other special flight characteristics.**

- Resolving horizontal distribution and errors introduced by advection through multiple platforms (depending on complexity of mission)
- At least 24 hour capability for diurnal patterns
- Seasonal measurements
- global (land and sea)

**Communication needs such as real-time data or instrument control**

- Pressurized, temperature controlled hard-drive for on-board data storage
- Telemetry – over the horizon capabilities for control and data relay
  - o Data rate - > 1Mbps

**Mission Concept: Describe in as much detail as possible the measurement approach:**

**Provide a narrative describing a “day-in-the-life” of the mission.**

- Observe satellite data sets (MODIS, OCO etc), file flight plan
- Flight path varies according to changes in weather, input from in situ sensors, other uavs in swarm etc.

**Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.**

- Low as possible to 100m; appropriate to regime being measured (interferometer)
- Integration time of instruments is one determinant of speed.
- Speed of air mass being measured determines airspeed
- Racetrack pattern to follow air mass
- Multiple altitudes -- Ascending spiral for vertical measurements vs. stacked arrays of measurements

**Identify any special or unique platform or mission issues**

- Land fluxes are 10-50x greater than ocean fluxes.

# **Carbon Cycle, Ecosystems, and Biogeochemistry – Vegetation Structure, Composition & Canopy Chemistry**

**Critical Observation: Vegetation structure, composition, and canopy chemistry**

**Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.**

- Improved characterization of terrestrial biomass using hyperspectral imagery, LIDAR, Radar, Interferometric radar (p, x, band – veg)
- Leaf level chemistry (eg. lignin, xanthophylls, etc.)
- Canopy water content

**Explicitly state how this observation and measurement supports this Earth Science focus area.**

- Provides vegetation 3d structure, information on composition, and chemistry
- Elucidates functional groups and physiological impacts on carbon cycle

**Explicitly state the advantage of using a suborbital platform for this measurement.**

- Currently, these measurements are not available from space platforms, but are critical parameters for understanding the terrestrial carbon cycle.

**Identify other cross-cutting areas impacted by this observation.**

**Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:**

**Instrument / Payload characteristics (type, weight, volume, power, environmental considerations, and access such as sampling or viewing ports)**

- Radar
  - Interferometric (p=ground return, x=top of canopy, L=structure)
  - <300kg (includes antennae, INU, data system)
  - <1m<sup>3</sup>
  - 2-3 Kw
  - antennae mounts
  - 5-10m horizontal; 1m vertical
  - 5-20km swath
- Imaging Spectroscopy

## **Carbon Cycle, Ecosystems, and Biogeochemistry – Vegetation Structure, Composition & Canopy Chemistry**

- Hyperspectral (350nm-2500nm), 10nm channels
- <50kg
- 0.5 m<sup>3</sup>
- 200w
- downward-looking port
- 5-20m horizontal
- 5-50km swath
- LIDAR
  - 2 frequency (525nm, 1050nm), waveform digitized
  - reference solid earth specs (30kg)
  - 600w
  - downward-looking port
  - 1m horizontal; 15cm vertical
  - <3km
- VHF Antennae
  - Need work

**Flight characteristics (location, altitude, endurance, season, frequency).  
Discuss number of platforms, formation flying, or other special flight  
characteristics.**

- Location – major ecological biomes distributed worldwide
- Altitude - 40,000ft
- Endurance – 12-24hrs
- Season – all seasons
- Weekly during green-up; during freeze and thaw; associated with disturbance
- Formation flying composed up 3-7 platforms
  - All carries P/L band radars
  - Subset carries hyperspectral and LIDAR
- Straight and level flight
- Sufficient geolocation and attitude through GPS or metrology

**Communication needs such as real-time data or instrument control**

- 1Mb/sec for telemetry and command and control
- Over-the-horizon capability

# **Carbon Cycle, Ecosystems, and Biogeochemistry – Vegetation Structure, Composition & Canopy Chemistry**

**Mission Concept:** Describe in as much detail as possible the measurement approach:

**Provide a narrative describing a “day-in-the-life” of the mission.**

- Ecological transects along ecological gradients
- Observations at flux tower locations and long term ecological experiments
- Optimize collection opportunities using meteorological data

**Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.**

**Identify any special or unique platform or mission issues**

- Proteus as a candidate as a transitional vehicle from manned to unmanned measurements, allowing instrument integration, remote operability, and testing
- Precise position and attitude information
  - sub-meter positioning for gps (30cm)
  - 5-10 arc sec attitude knowledge
  - active metrology for radar implementation

**Summarize the key elements of the mission concept for this measurement.**

## Key Messages

- We need high-quality hyperspectral thermal suborbital sensors
- Quality of sensor is tantamount – including stability over time
- We need low-and-slow as well as high-and-slow platforms
- Radar / 3D mapping capabilities (LIDAR)
- Fluorescence imaging
- Diurnal cycle observations
- Improved data mining / data fusion
- ID and long-term observations of source / sink instabilities
- Sea-land, sea-air, land-air – remote flux measurements
- Flask sampling from UAV's
  - Constituent sampling for all important biological gases
  - Continuous stream
- High precision GPS and pointing
- All different classes of platforms
- Contemporaneous phasing of instruments and platforms and science (co-evolution)
- Improved data user interface and rapid delivery (near real-time)
- Contemporaneous measurements of passive and active are important
- Better qualification of biomass combustion
- There are many timescales that are important in addition to diurnal – seasonal, annual and interannual